PERFORMANCE ENHANCEMENT OF SOLAR STILL USING PLANAR REFLECTOR

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ملخص البحث:

يستعرض البحث نتائج التجارب العملية التي أجريت على وحدتي تقطير لتحلية المياه باستخدام الطاقة الشمسية وقد أجريت هذه التجارب بهدف دراسة تأثير زيادة شدة الإشعاع الساقط على سطح المياه في المقطر على إنتاجيته. ولقد استخدم سطح مستوى عاكس تم تثبيته رأسيا في أحد الوحدتين وذلك لزيادة شدة الإشعاع الشمسي الساقط على سطح الماء في المقطر الشمسي واستخدمت الوحدة الأخرى للمقارنة. تما أجراء التجارب فوق سطح مباني الورش في كلية الهندسة جامعة طنطا بمدينة كفر الشيخ. تم تسجيل شدة الإشعاع الشمسي الساقط بالأضافه لقياس درجات الحرارة لكل من الماء داخل المقطر وسطح التكثيف الزجاجي وقد بينت النتائج مدى الزياده في إنتاجية المقطر عند إضافة السطح العاكس له.

ABSTRACT

Solar stills are attractive method to produce potable water from saline sea water in large areas of the world. The productivity of water from the still increases with increasing the radiation intensity on the still surface. The use of reflector to enhance the solar radiation on the evaporation surface of the still is promising. In the present work, an experimental investigation on the performance of solar still which is augmented by planar reflector is carried out. Two identical solar stills are designed and constructed with water surface area of (1m x 0.5m). For the purposes of comparison, a vertical mirror is supported in the east west direction on the back side of one still. Measurements of solar radiation intensity, ambient temperature, water temperature in the still and productivity are recorded in the day time. The effect of radiation enhancement on the still performance is discussed. Also, the work demonstrated to what extent productivity of the still can be improved.

KEYWORDS

Solar still- Radiation enhancement-Planar reflector, Water desalination

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INTRODUCTION

Application of solar energy for water desalination using basin-type solar still is one of the most ancient applications of solar energy field. The conventional solar still is simply a shallow pool of water in an enclosure with a transparent cover at the top. The interior surface of the enclosure is blackened to absorb solar radiation through the transparent cover which serves as the cooler surface upon which the condensation of water vapour occurs.

Summary of the effect of various parameters on the performance of basin-type stills is presented in referance [1]. The most important parameter affecting the performance of solar still is the intensity of solar radiation. The productivity of solar stills increases with the increase of solar radiation and vice versa. The average productivity of solar still obtained from eleven of the worlds largest solar stills, [2] is presented by the following relation:

$$P_d = 0.0393\, H_{sd}^{1.4} \qquad (1)$$

where P_d is the daily productivity in $L/(m^2$ .day) and H_{sd} is the daily solar radiation in MJ/(m^2.day).

The daily solar radiation on the surface of solar still is generally dependent on the system location, season and weather conditions. In general, these parameters are uncontrollable; therefore, radiation intensity on the still' surface is independent input parameter. However, solar radiation intensity on the surface of solar still can be enhanced with application of solar reflector. Reflectors have been suggested by many authors [3-8] to improve the performance of flat-plate collectors. In addition, solar pond with planar reflector has been theoretically analyzed and experimentally tested [9-11]. For solar stills, it seems reasonable to assume that reflectors can be made more cheaply than still, and thus hold the promise of reducing system cost by reducing the required still area. In this paper, an experimental investigation is carried out to evaluate the effect of radiation enhancement on the still surface using planar mirror and compare the performance of a simple basin type solar still with another one augmented by planar reflector.

THEORETICAL ANALYSIS

The solar still and flat mirror are east-west oriented, specular reflector, which share with the sill a common edge is south faced. The configuration of the system is shown in Fig. 2

The angle between water surface and reflector equals 90°

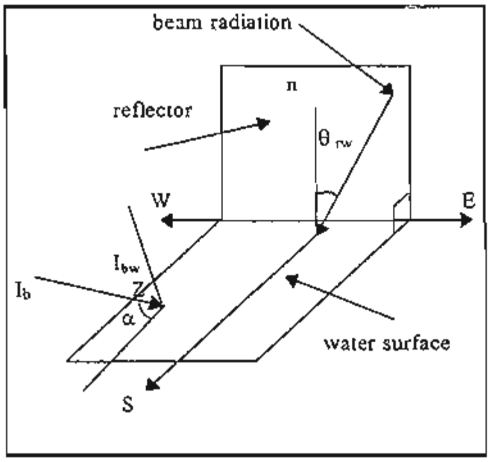

Fig.1: Configuration of the system

Radiation enhancement on the water surface

Radiation intensity on the pond surface at any instant during the day time can be calculated from the follwing relation:

$$q = (1-S_c)\,(I_b + I_{bw} F_{rw}.\rho_r .\cos\theta_{rw}) \tag{2}$$

where S_c and F_{rw} are the shading and exposure factors, respectively and θ_{rw} is the angle between reflected beam and normal to water surface, n. The incident beam on the water surface, I_{bw}, and diffuse component of radiation, I_{dw}, can be calculated from the following equations:

$$I_{bw} = I_b \cos Z \tag{3}$$

$$I_{dw} = C I_b \tag{4}$$

where I_b is the instantaneous value of incident beam radiation that depends on the time and location of solar system and is given as:

$$I_b = A\,Exp(-B/\sin\alpha) \tag{5}$$

The value of the zenith angle Z equals to $\frac{\pi}{2}-\alpha$, where α is the altitude angle which depends on the lactation, day time and time of the year and is given as follows:

$$\sin\alpha = \sin\delta\sin\phi + \cos\delta\cos\phi\cos w \quad (6)$$

where δ is the declination angle, obtained from this equation:

$$\delta = 23.45\sin\left[\frac{360}{365}(284+N)\right] \quad (7)$$

where ϕ is the latitude angle, w is the hour angle, N is the day number from 1[st] January and values of constants A, B and C are given in [12]. The exposure factor F_{rw} is defined as the fraction of water surface exposed to reflected radiation .On the other hand, the shading factor S_c is the fraction of the water surface which is in shadow.These factors depend on system geometry, (width and length ratios) location and time .The theoretical model calculating reflected radiation have been developed in detail by Grassie and Sheridan [5] and the effects of geometrical paramters and system location are analysed by Gad, et.al [9]. Exposure and shading factors can be evaluated for the proposed system using the model presented in [9], when the reflector tilt angle to the surface is $\frac{\pi}{2}$ and the width ratio is unity; the width ratio is defined as the ratio between the reflector width to the still width.

Productivity Enhancement of Solar Still

The rate of distillate D produced by the still per unit area of the cover depends on the time of the day . Its instantaneous value is given as follows .

$$D = \frac{q_e}{L_w} \quad (8)$$

where q_e is the instantaneous heat of evaporation exchanged between the water in the basin and the still cover and L_w is the latent heat of water at the cover temperature . The heat transmitted by evaporation q_e per unit area of the cover (W/m^2) is a function of glass temperature and water temperatures and is given by Dunkle[13] as:

$$q_e = 0.0061\left[(t_w - t_g) + \left(\frac{P_w - P_{wg}}{0.265 - P_w}\right)(t_w + 273)\right]^{\frac{1}{3}} * (P_w - P_{wg})L_w \quad (9)$$

where P_w and P_{wg} are the vapour pressures on the water and glass surfaces, respectively

(M N/m^2), t_w and t_g are the water and glass temperature respectively and L_w is the latent heat of evaporation of water (J/Kg) at saturation temperature t_w. Two other modes of heat transfer are carried out in the solar still, these modes are radiation and convection heat transfer from water to glass. The radiation and convection heat transfer rates, which are depentent on the water surface temperature and glass temperature can be evaluted from the following equations:

$$q_r = F_{wg}\sigma\left[T_w^4 - T_g^4\right] \tag{10}$$

$$q_c = 0.883\left[\left(T_w - T_g\right) + \frac{P_w - P_{wg}}{0.265 - P_w}\left(T_w + 273\right)\right]^{1/3}\left(T_w - T_g\right) \tag{11}$$

where F_{wg} is the shape factor of diffuse radiation between water surface and cover, and σ is the Stefan-Boltzmann constant. The expression for F_{wg} is given as follows:

$$F_{wg} = \frac{1}{\frac{1}{\varepsilon_w} + \frac{1}{\varepsilon_g} - 1} \tag{12}$$

where ε_w, ε_g are the emissivity of the water surface and glass cover respectively.

The calculation procedure through which the instantaneous productivity of the still can be evaluated as presented in [13]. In this procedure, values of heat transfer coefficients, specific heat of still, ambient temperature and wind speed must be initially specified or determined. Also, the initial temperature of water in the still is specified. Instantaneous values of solar radiation are measured or evaluated using the radiation model. Heat and mass balance calculations are performed, where the glass temperature is calculated and corrected through the iteration procedure. Subsequent calculations of temperature rise of both water and glass are carried out with varying the input radiation to the system. Equations (8) and (9) are used to evaluate the productivity of the solar still.

The procedure described above can be applied when radiation is enhanced on the surface of the still to evaluate the increase in productivity due to radiation enhancement. In addition, by knowledge of water and glass temperatures different heat transfer rates can be calculated.

EXPERIMENTAL SET-UP

Figure (1) shows a sectional elevation of the experimental solar still, which is augmented by planar reflector. In addition, an identical solar still without reflector is fabricated and located in the same conditions of solar radiation and ambient temperature for the purpose of comparison. The inside wall of still is fabricated from a steel sheet of 2 mm thickness to form, by welding, a basin of 1 m length and 0.5 m width . For one of the

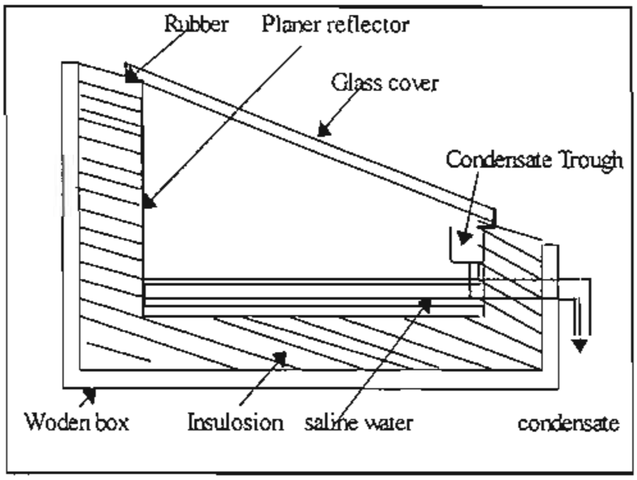

Fig. 2 : Sectional Elevation of the solar still

two stills, on the inside wall which is opposite to the south direction, a reflector surface is supported. The steel basin of the solar still, which is painted from the internal walls and base with blackboard paint, are insulated with 10 cm wooden sawdust from the outside surface. Transparent surface which operates also as a condenser is a window glass of 3 mm thickness and is inclined at an angle of (15)degree. The south faced reflector which has a reflectivity of 0.75 is 1 m high and 0.5 m width, and vertically supported in common edge with the base of basin. Temperatures of water in the stills and glass surfaces is measured by copper-constantan thermocouples. Solar radiation on the horizontal surface is also recorded during the experimental work. The productivity of each of the two stills is evaluated by measurement of the accumulated volume of water for each of them each hour during the day time. The experimental set-up is prepared and located on the roof of abuilding in the Faculty of Engineering, Tanta University, in Kafr Elsheekh city (latitude 30^{o} 6' N)

RESULTS AND DESICCATION

Short term experiments on the two experimental solar stills is carried out to evaluate the effect of radiation enhancement on the performance. Data are recorded and compared on the same graph for each of the two stills. Figures 3 and 4 show the variation of both water and glass temperatures for the two experimental solar stills. As the solar radiation intensity is enhanced in the second still, it is expected that the water temperature in this still will be higher than that of the first one. On the other hand difference in temperatures of glass cover of the two stills is negligible (Fig.3). Solar radiation on the horizontal surface daring the day time

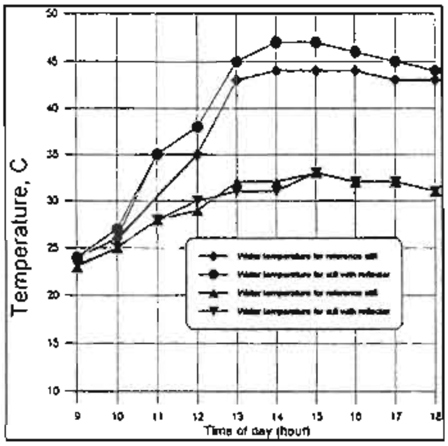

Fig. 3 Variation of temperature during the day 8/9/1998

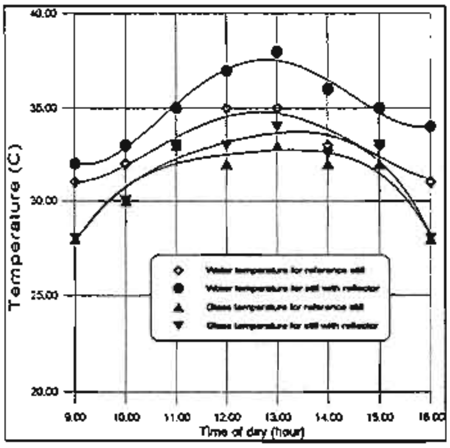

Fig. 4 Variation of temperature during the day 16/9/1998

is shown in Fig.5. According to the field recorded data, values of different heat transfer modes are evaluated according to the model given by [13]. Figures 6 and 7 show the variation of heat transfer rates for the two experimental stills. As expected, enhancement of solar radiation on the surface of the second still results in increase in heat transfer by convection and radiation from water surface to the glass cover (Fig.7) However, intensity of heat transfer due to evaporation of water vapor and that due to radiation from glass to ambient atmosphere take higher values compared with radiation and convection from water to glass as shown in Fig.8.

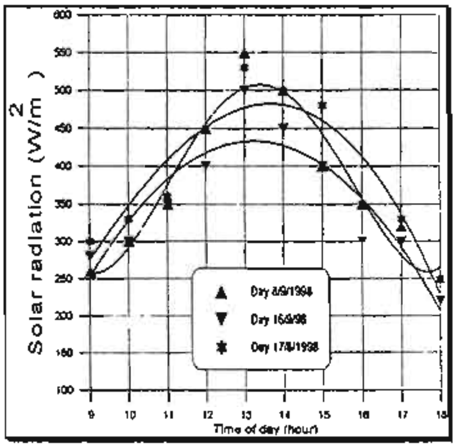

Fig. 5 Varaition of the solar radiation on the horizontal surface during the day time.

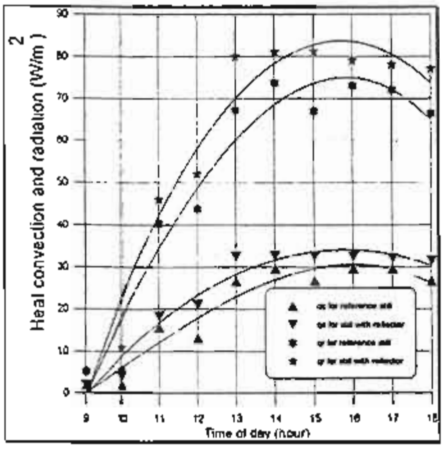

Fig.6: Variation of convection and radiation heat during the day 8/9/1998.

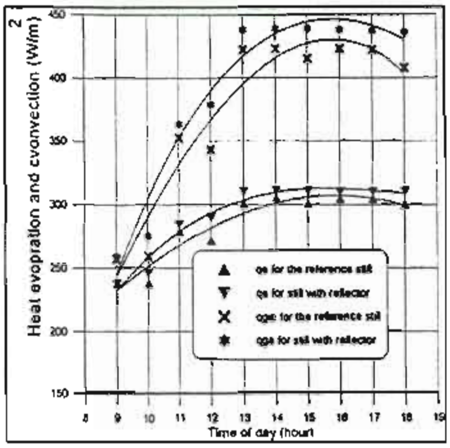

Fig.7: Variation of evopration and convection heat during the day 8/9/1998.

To evaluate the increase in productivity of solar still due to radiation enhancement on the water surface, mass of water condensed during the day time for the two solar stills and percentage increase in the productivity is evaluated.

Figure 8 shows the hourly variation of accumulated productivity enhancement for three days of the experimental tests. It can be noted that the maximum value of the percentage increase in the productivity occurs nearly at the hour of peak solar radiation . For the aperating days of the experimental tests, the percentage increase in solar radiation on the water surface during the day time is evaluated as given by [9]. This increase of radiation intensity is evaluated as 27%. Referring to Fig. 8, it can be observed that the hourly enhancement in productivity ranges from 9% to 21% .

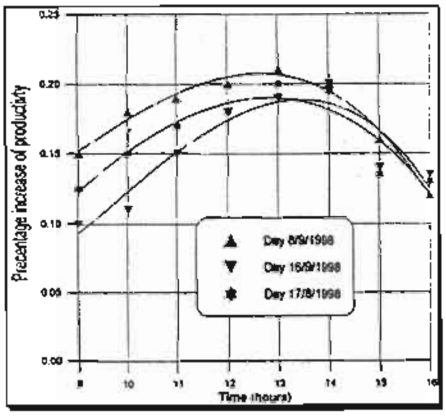

Fig.8 Hourly increase of productivity during the day time

CONCLUSION

A simply constructed , solar still augmented by planer reflector has been presented, in which solar radiation on the water surface is enhanced. A reference basin-type solar still which has the same design and construction is used for comparison. Analysis of the experimental results has shown that:

1-With application of planar reflector, productivty of basin -type solar still can be enhanced, and the daily enhancement in productivty during the period of experimental work ranges from 9% to 21%.

2-Enhancement of solar radiation on the surface of solar still increases both the water temperature and the temperature difference between the water and glass surfaces.

3- Evaluation of convection and radiation heat transfer rates through the solar still has shown that, the rate of convection heat transfer due to evopration of water and radiation from glass to ambient atmospher increase with the increase in radiation intensity.

REFERENCES

1- M.M. Elsayed, I.S. Taha and J.A. Sabbah, " Design of Solar Thermal Systems" , Scientific Publishing center ,King Abdulaziz University Jeddah, 1994.

2- J.A. Eibling ,S.G. Talbert and G.O.G. lof , "Solar Stills for community Use- Digest of Technology", Solar Energy13, PP.263-276, 1971

3- D.C. larson, "Optimization of Flat - plat collector -Flat Mirror System" , Solar Energy ,vol. 24, PP 203-207, 1997

4- I.S. Taha and S.M. Eldighidy, " Effect of off- South Orientation on Optimum conditions for Maximum Solar Energy Absorbed by Flat- plat Collector Augmented by Plane Reflector " Solar Energy ,Vol.25, PP.373- 379, 1980.

5- S.L. Grassie and N.R. Sheridan, "The Use of Planar Reflector for Increasing the Energy Yield of Flat - Plat collector", Solar Energy , Vol.19, PP.663-668,1977.

6- D.K. Mcdaniels ,et, al., "Enhanced Solar Energy collection using Reflector -Solar Thermal collector combinations", Solar Energy ,Vol . 17, PP.277-284,1975.

7- S.C. Seitel, "Collector Performance Enhancement with Flat Reflectors", Solar Energy , Vol . 17 , PP.291- 295, 1975

8- F.A. Rudlaff ,S.R. Swanson and R.F. Boehm ,"Computer Simulation Results for planar Reflector and Flat - Plat Solar Collectors". ASME paper, Vol .102, PP .166- 172, 1980.

9- H. E. Gad, A. M. Hamed and S.S.EL-Sayed, "Radiation enhancement using planar reflector with solar pond", 2nd International Engineering Conference , Mansoura, Egypt, 1997.

10- A.M. Hamed, Gad and S.S. El -Sayd, "Performance of a Small Sattless Solar Pond Augmented by Planar Reflector" Mansoura Engineering Journal (MEJ) Vol.22,N0.2, 1997.

11- W.C. Dickinson and P.N.cheremisisoff, "Sallow Solar Ponds in Solar Energy Technology Itand Book", New York ,1980.

12- J.S. Hsieh " Solar Energy Engineering " New Jersey, 1986.

13- R.V. Dunkle , "Splar water Distillation ; The Roof Type Still and a Multiple Effect Diffusion Still", International Heat Transfer Conference University of Colorado ,U.S.A. , part 5,895- 902,1961.

NOMENCLATURES

A,B,C ; constants used in eqn 3,4

D : rate of distillate produced by the still per unit area, $L/hr.m^2$

F_{rw} : exposure factor

H_{sd} : daily solar radiation ,MJ/m? day

I : beam radiation ,W/m^2

L : latent heat of evaporation of water J/kg

P : water vapor pressure MN/m^2

q : rate of heat transfer,Kw

S_c : shading factor

t : temperature, C°

Z : zenith angle, deg .

α : altitude angle, deg.

B_{rw} : reflected bean tilt angle on the still surface

ρ_r : reflectivity

Subscripts

a: ambient

b: beam

d: deffuse

e: evaporation

g: glass

wg: water properties glass temperatur